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Unit Maintenance Aerial Recovery Kit (UMARK)

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13. ABSTRACT *(Maximum 200 words)*

This report describes the activities performed under Contracts DAAJ02-92-C-0048 and DAAJ02-97-M-0004, to produce prototype UMARK kits. The objective of the program was to develop a means of aerial recovery of inoperative and lightly and heavily damaged helicopters using medium-lift and heavy-lift helicopters as the recovery vehicles. The UNMARK is the result of this work. UMARK can recover the following helicopters (and can easily accommodate others): AH-64, AH-64 Longbow, CH-47, UH-60, AH-1 and UH-1 (all Army models), OH-58 (A/C and D), and RAH-66 Comanche. UMARK is lightweight, compact and can fit in a HMMWV, CUCV, van, pickup truck, or helicopter. Three people can fully rig any helicopter in 15 minutes or less. It is adaptable to future requirements without extensive modifications or additions to the Kit. Kit complexity is minimized to reduce training, reduce rigging time, and heighten safety. UMARK is a major improvement over previous methods of aerial recovery.

This report discusses all tasks performed under these contracts, including: Design and analysis, prototype fabrication, limit and ultimate strength testing, ground testing to develop and verify rigging procedures, and flight testing to fine-tune rigging procedures and verify Kit effectiveness.

14. SUBJECT TERMS

Helicopter Recover	AH-64	CH-47	RAH-66 Helicopter Rigging
Aerial Recovery	OH-58	CH-47	Flight Test
Damaged Aircraft	AH-1	UH-60	Lightweight Sling

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1. Introduction

The overall objective of this program was to develop a means of aerial recovery of inoperative helicopters, using medium-lift and heavy-lift helicopters as the recovery vehicles. The Unit Maintenance Aerial Recovery Kit (UMARK) is the result of this work. The Kit was required to be universal to the greatest extent possible. It was to be adaptable to a variety of future and potential configurations, without requiring extensive modifications or additions to the current Kit equipment. The Kit was required to be lightweight, to be handled and rigged by a three-person crew. It needed to be compact, to be easily transportable via a single vehicle (van, pickup truck, HMMWV, CUCV or helicopter). Rigging needed to be accomplished quickly, to reduce exposure of riggers and aircrew in hostile environments. Complexity was kept to a minimum to reduce training requirements and simplify Kit use.

The UMARK Kit consists of a lightweight assortment of flexible lifting members (slings and lines), metal fittings, and elastomeric components, which allow rigging and recovery of a wide array of U.S. Army helicopters (Ref Table 1). Figure 1 shows a CH-47 using the UMARK Kit to recover a (simulated) downed UH-1. Figure 2 shows the UH-1 during recovery. Figure 3 shows all UMARK Kit components; the metal fittings and elastomeric components are to the left, and the slings are to the right.

The UMARK Kit is the third step in the evolution of Aerial Recovery Kits (ARK). The first step in the evolution was the original Army ARK. It was made entirely of metallic components (metallic fittings and hardware, and steel cables). The full Kit weighed in excess of 1,200 lbs.; it was dangerous to use due to the complex rigging procedures and Kit construction; and it didn't have the capability to recover all Army aircraft, especially those in the modernized fleet.

The next step was the Interim UMARK (IUMARK), developed during the Desert Storm conflict to recover damaged aircraft. This Kit was a great improvement over ARK. It weighed approximately 650 lbs., an improvement of almost 100% over the ARK; it allowed recovery of damaged aircraft; and it utilized modern materials to improve handling and save weight. This success of this Kit proved the concept and spawned the development of the UMARK.

The current UMARK kits weigh 300 lbs., are approximately 350 lbs. lighter than the IUMARK, and 900 lbs. lighter than the ARK; this weight advantage (without compromising strength) was achieved through the extensive use of Spectra fiber for the slings and tiedowns. They are able to recover a large number of Army aircraft including those in the modernized fleet. They are capable of recovering heavily damaged aircraft (tail boom or rotor head not intact). They are designed to be adaptable to future requirements. The rigging procedures are simple and consistent from one application to the next. A three-person crew can rig a helicopter in fifteen minutes or less. Safety is much improved over its predecessors. Overall, UMARK is a great improvement over the IUMARK, and an order-of-magnitude improvement over ARK.

This report describes the design and development, static testing, and flight testing of the Unit Maintenance Aerial Recovery Kit (UMARK). This work was performed under contracts DAAJ92-02-C-0048 and DAAJ02-97-M-0004; work was begun in 1993, and completed in 1998.

Table 1 - Helicopter Model & Recovery Rigging Configuration

Disabled Aircraft	Design Recovery Weight lbs. (kg)	1 Hook Short Line	1 Hook Long Line	2 Hook Short Line	2 Hook Long Line	Recovering Aircraft
AH-64	20,000 lbs. (9,090 kg)	X	X	X		CH-47 (1- and 2-hook)
AH-64 Longbow	20,000 lbs. (9,090 kg)	X	X	X		CH-47 (1- and 2-hook)
CH-47	26,000 lbs. (11,818 kg)			X		CH-47 (2-hook)
UH-60	14,000 lbs. (6,364 kg)	X	X	X		CH-47 (1- and 2-hook)
AH-1 (All Army Models)	8,000 lbs. (3,636 kg)	X	X			CH-47 (1-hook)
UH-1 (All Army Models)	6,000 lbs. (2,727 kg)	X	X			UH-60 (1-hook) or CH-47 (1-hook)
OH-58D	5,500 lbs. (2,500 kg)		X			UH-60 (1-hook) or CH-47 (1-hook)
OH-58A/C	3000 lbs. (1,364 kg)		X			UH-60 (1-hook) or CH-47 (1-hook)
RAH-66 Comanche	12,800 lbs. (5,818 kg)	X	X	X	X	CH-47 (1- and 2-hook)

Figure 1 - UMARK-Rigged UH-1, ready for recovery.

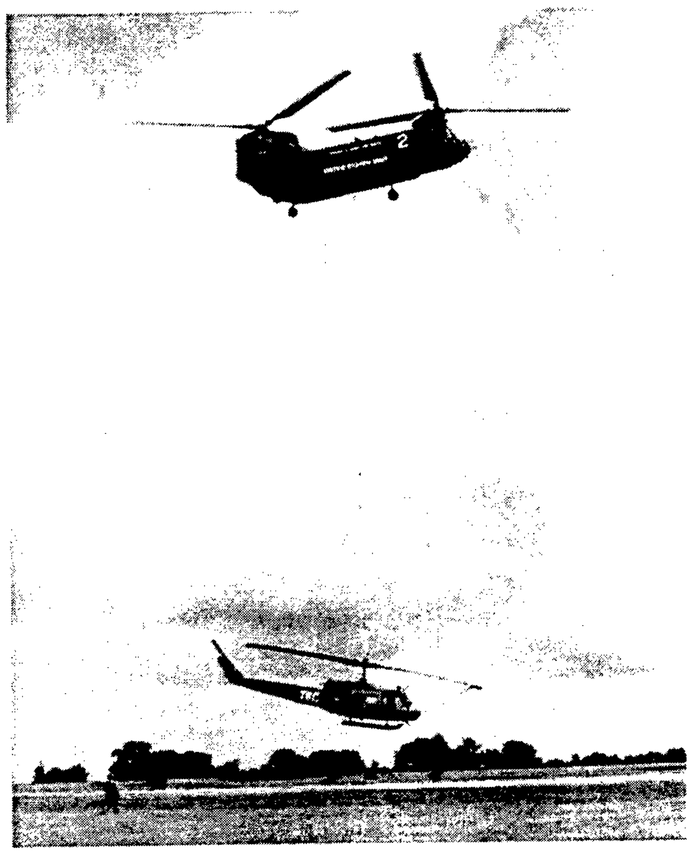

Figure 2 - UMARK Long Line Recovery of UH-1

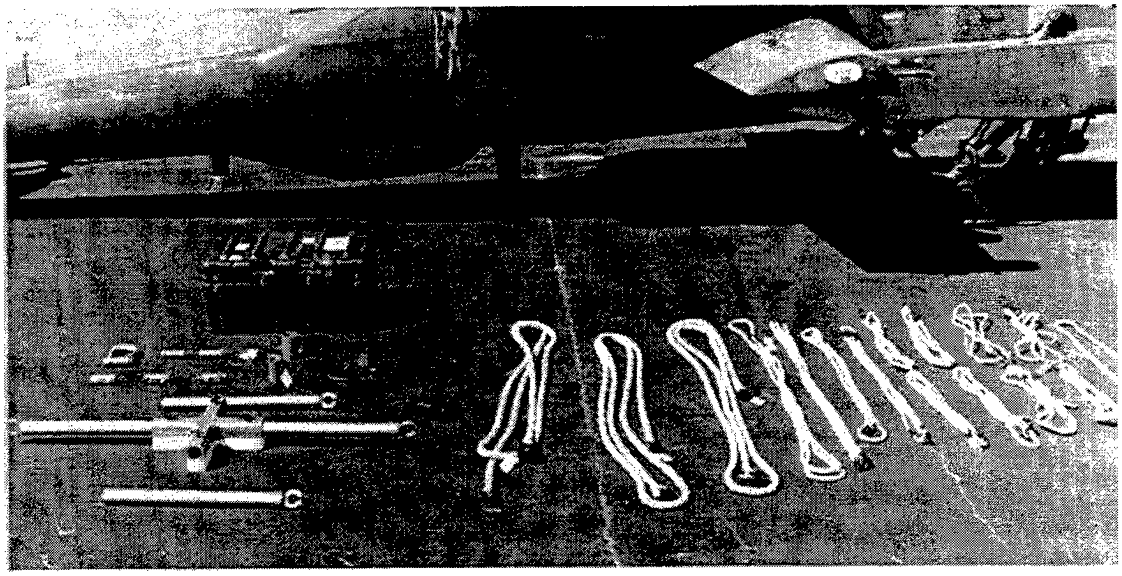

Figure 3 - UMARK Kit Components

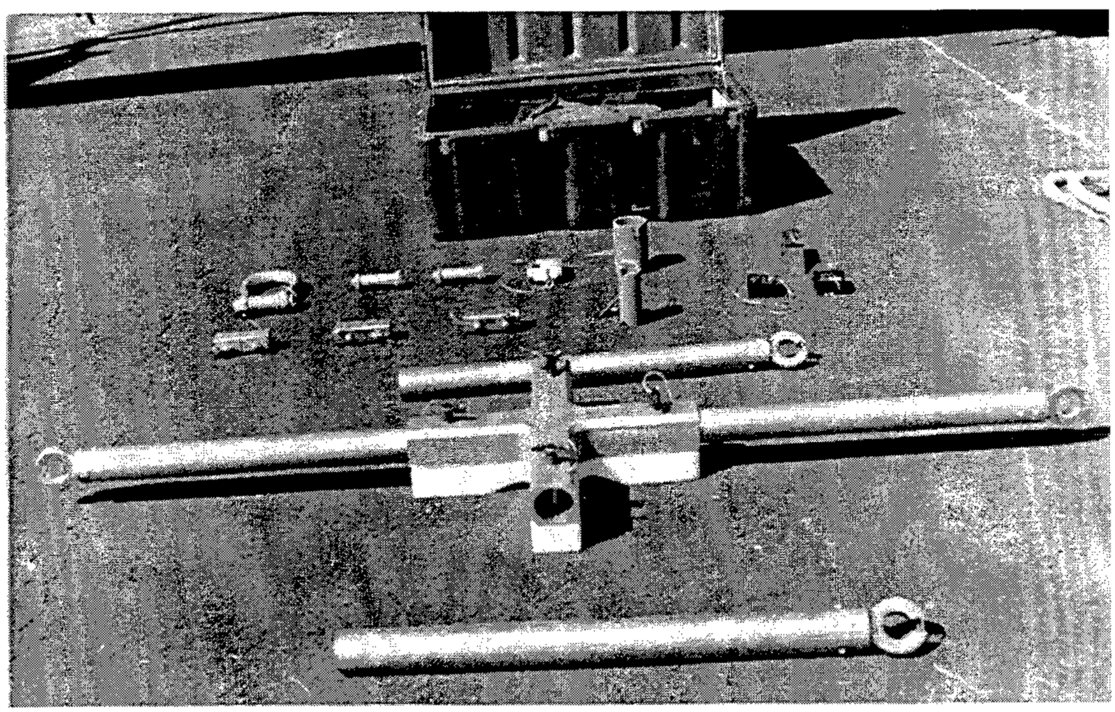

Figure 4 - UMARK Hardware Components

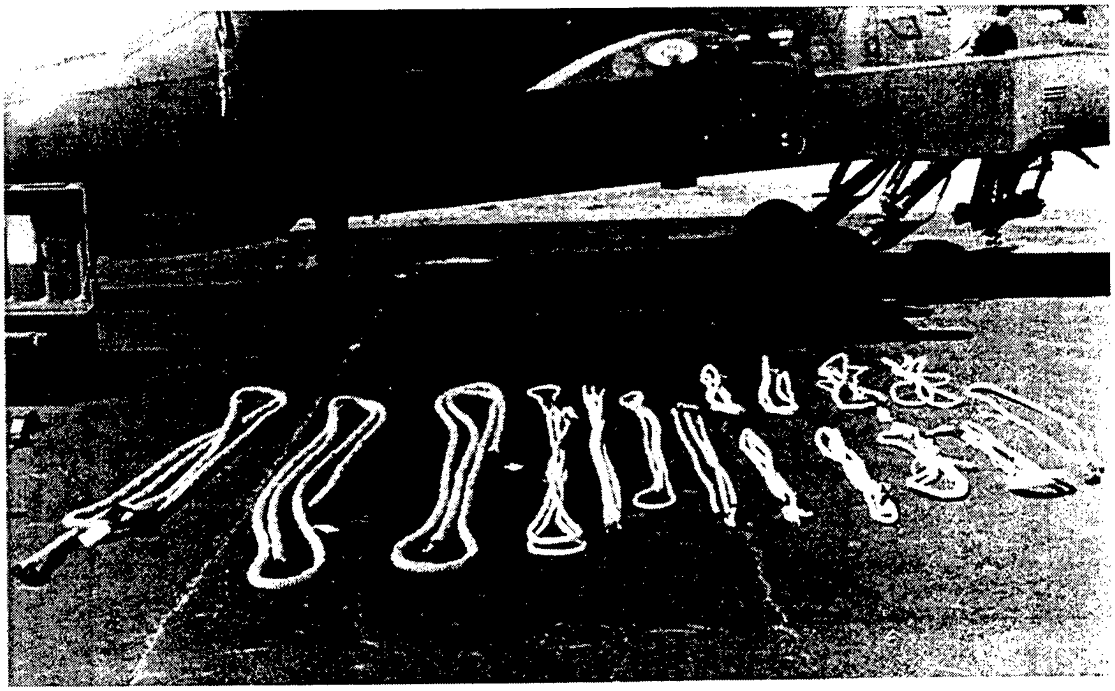

Figure 5 - UMARK Kit Slings & Tiedowns

Several major tasks were required by the program. The first task was the design and stress analysis of the basic Kit. This was followed by production of four prototype Kits and test articles. The test articles were used for component testing, to ensure that the strength requirements were met. The prototype kits were initially used for ground testing and simulated recoveries (lifting a helo using a crane). Rigging procedures were developed and documented during this phase. The Kits were certified airworthy, allowing certain helicopters to be recovered using certain rigging configurations and recovery aircraft (ref. Table 1 for aircraft and rigging configurations). Flight-testing was carried out, to prove the kits in actual recovery situations and to finalize the rigging procedures. Maintenance procedures for the Kits themselves were developed and documented. The final task was reporting of all program activities in the final report.

1.1 Inoperative Helicopter Models & Recovery Rigging Configurations

Table 1 lists the helicopter models and recovery configurations that were analyzed. Included are the model, maximum recovery weight, and rigging configuration. A minimum safety factor of 5:1 was maintained for all configurations. One-hook configurations utilize the center hook on the CH-47 or the single UH-60 hook. Single-hook configurations integrate the tail boom slings with the main rotor sling; two-hook configurations rig the main rotor slings to the forward or center hook, and tail boom to the aft hook. Short line rigs suspend the aircraft approximately 60 ft below the lifting helicopter; long line rigs use an additional 30 ft sling, for a total of approximately 90 ft. Figure 2 illustrates a one-hook long-line rig for the Huey.

1.2 Damaged Helicopter Models & Recovery Rigging Configurations

In addition to inoperative helicopters, the UMARK Kit supports recovery of certain damaged helicopters. Table 2 details supported aircraft and the types of damage for which rigging procedures, and loads analysis, has been performed.

Table 2 - UMARK Rigging Options for Damaged Aircraft

Damaged Aircraft	Rigging Option / Allowable Damage
AH-64	1. Damaged Tail Boom, Main Rotor or Transmission
AH-64 Longbow	1. Damaged Tail Boom, Main Rotor or Transmission
UH-60	1. Damaged Tail Boom
	2. Damaged Main Rotor or Transmission
AH-1 (All Army Models)	1. Damaged Tail Boom
	2. Damaged Main Rotor or Transmission
UH-1 (All Army Models)	1. Damaged Tail Boom, Main Rotor or Transmission
OH-58A/C	1. Damaged Tail Boom
	2. Damaged Main Rotor or Transmission
OH-58D	1. Damaged Tail Boom
	2. Damaged Main Rotor or Transmission

1.3 Program Tasks

The following tasks were performed. The development process was an iterative one, and involved the technical services of AATD personnel, Kaman Aerospace, and Cortland Cable Co.

1.3.1 Design and Analysis

The UMARK was designed to suspend the helicopter from the main rotor area. This part of the helicopter normally carries the full loaded weight in flight, thus it's the most desirable location to lift a downed helo. The UMARK was also designed to maintain aircraft stability during flight. This was accomplished by three means. First, a nose-down hang angle during flight was maintained by use of a tail boom sling. This counteracts any potential lift, and prevents the aircraft from swinging forward and aft. Second, the rotor blades were secured using tie-downs and blade sleeves to rig the blade tips to the fuselage. These components prevented blade flapping and fixed the rotor blades to the fuselage, preventing the fuselage from rotating under the rotor head. Third, when required a drogue chute was attached at the aft end of the tail boom. This moved the aerodynamic center as far aft as possible, to prevent yaw oscillations and swinging side-to-side.

The UMARK Kit consists of three types of components- "high-strength" suspension components, "low-strength" suspension components, and blade rigging components. All components were designed to a limit-load safety factor of five; that is, their ultimate strength was five times the maximum working load. This requirement was demonstrated for all components by analysis and test.

The "high-strength" components consist of the high-strength slings (30ft with and without bridle), the sling links, the spreader bar assembly, the shackle, hook thimble, and the lifting clevis assembly. These components are designed to carry the weight of the entire aircraft. Most components (including all slings, sling link,

shackle, and crossbar assembly) were designed to a minimum breaking strength of 100,000 lbs. The lifting clevis is designed to 40,000 lbs. minimum strength- it is only used for the OH-58, UH-1 and AH-1 series aircraft which weigh 8000 lbs. or less.

The "low-strength" items are those designed to adjust the hang angle, or are used in parallel to lift the aircraft (94D519-1 slings). This group consists of the "low-strength" slings, and the box link. The slings were designed to a working load of 5300 lbs., or a minimum breaking strength of 26,500 lbs. The limit design load for the box link was 2152 lbs., based upon the maximum-load rigging case. That case is the UH-60 short line, Aft CG. The ultimate design load for the box link was 10,760 lbs.; the stress analysis shows it would support in excess of 17,700 lbs..

There are two groups of blade rigging components. The first group were designed to 7000 lbs. strength; they are used to secure the blades to the fuselage and prevent blade flapping. These components are the adjustable-length tiedowns, the sling extensions, and the blade sleeves. The second group was designed to prevent rotation of the fuselage under the blades; these were designed to 4000 lbs. breaking strength. These components are the fixed-length tiedown and the snapless tiedown.

1.3.2 Prototype Fabrication

Four prototype Kits were fabricated to the design. Figure 3 shows the assemblage of components for one complete Kit. Not shown is the CH-47 Hook Thimble, P/N 94C533-1, which was added following flight tests. Figure 4 shows all metallic components and hardware. Figure 5 shows all slings, and tiedowns. All components are boxed in NBC-sealed cases, with three cases holding all components for one Kit. Each case can be easily handled by two personnel. Box

1 contains all slings; Box 2 contains the spreader bar used for the AH-64 Longbow and OH-58D; and Box 3 contains all ancillary equipment.

1.3.3 Component Testing

Each UMARK Kit component was produced to its detail design, and was tested to working and ultimate loads. Component testing is detailed in the Airworthiness Substantiation Document. Table 3 lists the mechanical components that were tested, and their respective failure loads. All components failed at ultimate loads higher than the requirement, thus exhibiting positive margin relative to the required load and safety factor.

Table 4 lists the slings and other components that were tested, and their respective failure loads. As with the mechanical components, all components failed at ultimate loads higher than the requirement, thus exhibiting positive margin relative to the required load and safety factor. Based on the successful design substantiation testing, airworthiness releases for static lift in flight testing were obtained.

Table 3 - Mechanical Components Ultimate Test Data

Component	P/N	Design Ultimate Load	Failure Load
Cross Bar Assembly	94H501-1	22,500 lbs. horizontal	24,660 lbs.
Cross Bar Assembly	94H501-1	100,000 lbs. vertical	100,000 lbs.**
Lifting Clevis Assembly	94D509-1	40,000 lbs.	40,000 lbs. *
Shackle Assembly	94D514-1	100,000 lbs.	120,000 lbs.
Sling Link Assembly	94D523-1	100,000 lbs.	100,000 lbs. **
Box Link Assembly	94C524-1	10,760 lbs.	10,760 lbs. *
CH-47 Hook Thimble	94C533-1	100,000 lbs.	127,000 lbs.***

* No failure occurred at noted load.
** By analysis- ref Airworthiness Substantiation Document
*** Failure occurred in the sling eyelet looped around the Thimble, not the thimble itself.

Table 4 - Sling & Miscellaneous Components Ultimate Test Data

Component	P/N*	Design Ultimate Load	Failure Load
Low Strength Sling 150" with Bungee	94D519-1	26,500 lbs.	31,750 lbs.
Low Strength Sling 153"	94D519-2 (was –3)	26,500 lbs.	31,750 lbs.
Low Strength Sling 208"	94D519-3 (was –5)	26,500 lbs.	31,750 lbs.
Low Strength Sling 360"	94D519-4 (was –7)	26,500 lbs.	31,750 lbs.
Low Strength Sling 120"	94D519-5 (was –9)	26,500 lbs.	31,750 lbs.
High Strength Sling 30 ft	94H520-1	100,000 lbs.	142,500 lbs.
High Strength Sling 30 ft With Bridle	94H520-2 (was –3)	100,000 lbs.	142,500 lbs.
Adjustable-Length Tiedown	94H521-1	7,000 lbs.	9,200 lbs.
Sling Extension	94H521-2 (was –005)	7,000 lbs.	9,200 lbs.
Fixed-Length Tiedown	94C522-1 (was –001)	4,000 lbs.	9,200 lbs.
Snapless Tiedown	94C522-2 (was –011)	4,000 lbs.	9,200 lbs.
Blade Sleeve Assembly	94J516-1	7,000 lbs.	8,700 lbs.

* Sling Dash numbers have changed since testing. Construction is identical.

1.3.4 Ground Testing

Ground testing was performed as the initial method of functional testing of the UMARK Kits. The ground test program was also used to improve the rigging techniques and configurations.

Ground testing consisted of rigging various helicopters (AH-64, UH-1, and OH-58) per the rigging procedures, and lifting them with a crane. Table 6 shows the AH-64 Longbow during initial ground testing. Each component and its attachment to the helicopter were scrutinized, and changes and improvements were made where necessary. A number of minor changes were made to the rigging procedures and sling locations to improve stability and ease of rigging. Figure 7 shows the OH-58 during ground testing. This photograph shows the lifting clevis supporting the weight, with the safety slings hung loosely around the

rotor blade hubs. Figure 8 and Figure 9 show views of the UH-60 during ground testing. Figure 8 shows the original tail rigging configuration, which ground testing showed was unsuitable. Figure 9 shows the final location of the UH-60 tail rigging. Several alternate locations were tried, with this being the optimal choice.

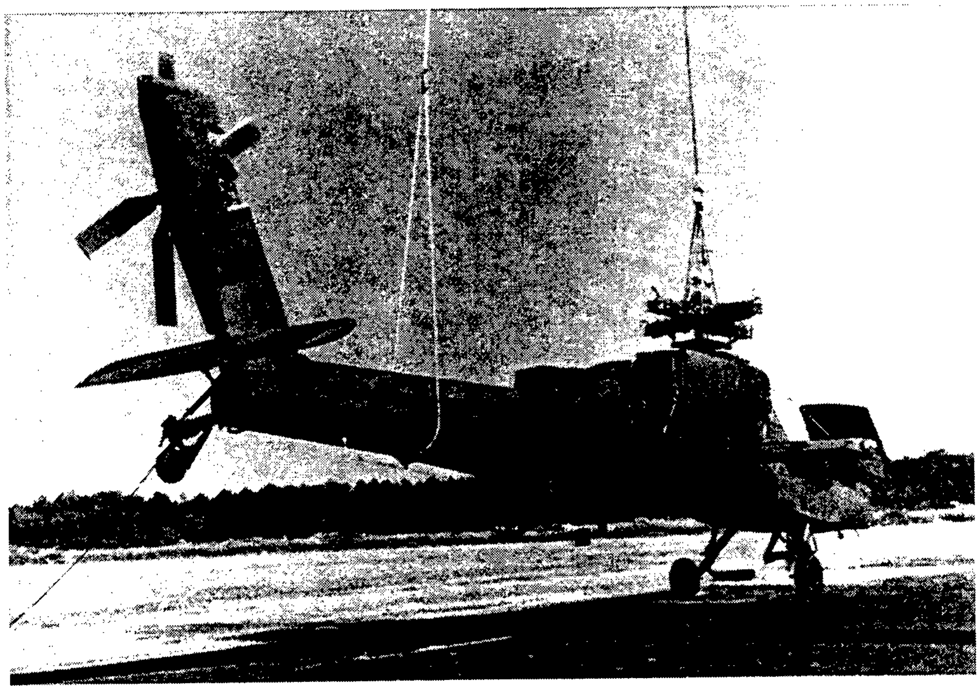

Figure 6 - AH-64 Ground Testing

Figure 7 - OH-58 During Ground Testing

Figure 8 - UH-60 Showing Tailwheel Rigging

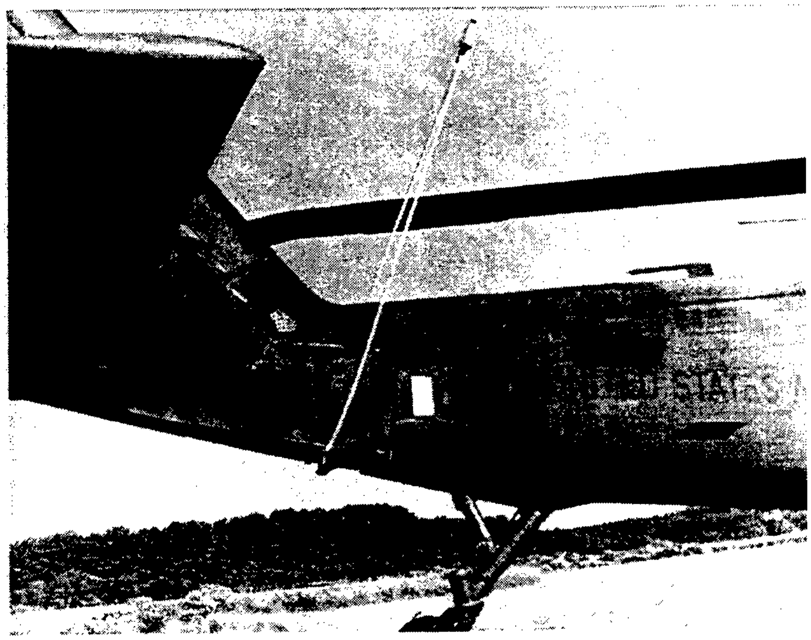

Figure 9 - UH-60 Final Tail Rigging Location

In some cases, slings lengths were changed as well, by folding longer slings or box link rigging changes. Figure 10 shows the AH-64 Longbow (simulated) rigged with a double-folded tail sling to adjust the length of the tail rigging. In other cases, multiple rigging methods were instituted as backup. Figure 11 shows the OH-58 rotor head rigging. Note the backup slings at the rotor head, while the clevis carries the load.

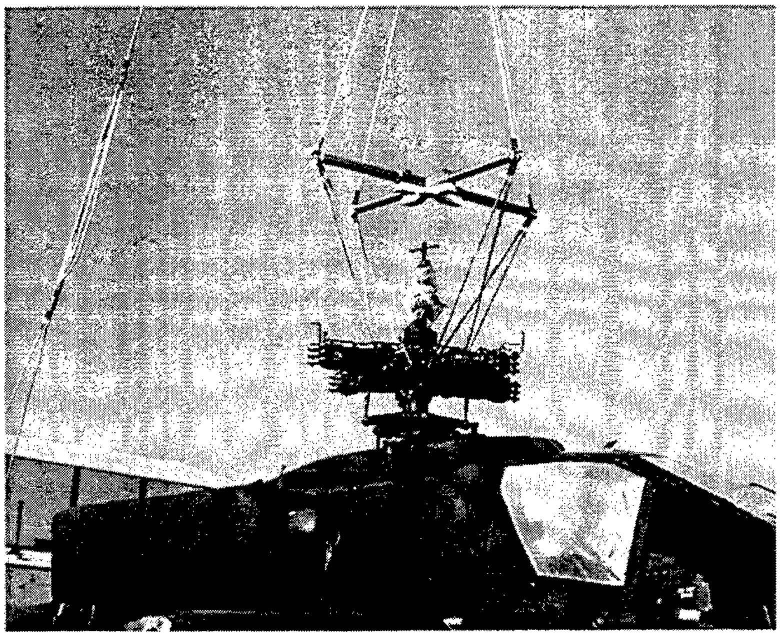

Figure 10 - AH-64 Longbow (Simulated) Rig Showing Doubled Tail Sling

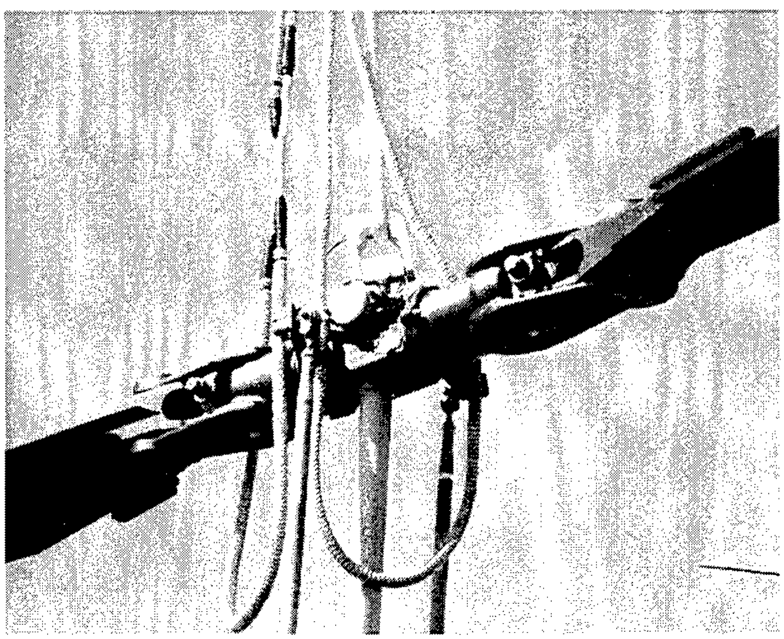

Figure 11 - OH-58 Rotor Rigging

The ground test program resulted in much-improved rigging procedures, better helicopter stability, simpler procedures, and better reliability for the UMARK Kits and the slung helicopter components. It also offered the opportunity to verify assumptions about rigging methods. The rigging procedures and configurations that resulted from the ground testing, combined with the successful component testing, were then approved for use in the flight-test program.

1.3.5 Flight Testing

Flight-testing was the final step to certifying the UMARK Kits. This consisted of rigging each helicopter (ref. Table 1), hooking up to a recovery aircraft (a CH-47 was used), lifting the rigged helicopter to a sufficient altitude, and flying a simulated recovery mission. Each helicopter was flown several times at increasing airspeeds; the behavior of the slung aircraft was used to determine maximum safe airspeed, and changes or additions to the rigging apparatus. The rigging procedures and configurations were modified to include maximum airspeed and any required rigging changes. Following the successful completion of flight testing, the UMARK Kit was certified airworthy. The complete list for which UMARK is certified is noted in Table 1.

1.3.6 Rigging Procedures

Rigging procedures were developed to ensure proper use of the UMARK Kit. These procedures were initially developed during the initial design and analysis tasks. They were updated as the design progressed and components and methods evolved. The ground test program produced many improvements in both rigging methods and utilized components; the rigging procedures were updated each time. The flight test program further fine tuned the procedures, and added data (such as maximum airspeed). The rigging procedures are documented separately in the UMARK Technical Manual (Kaman Aerospace Report No. R-2188). Use of the prototype Kits and lessons learned during recovery of various helicopters in training and use, brought about a further

iteration of the procedures. These were documented in Revision A (the current revision) of the UMARK Technical Manual.

1.3.7 Maintenance Procedures

The final documentation task was development of maintenance procedures for the Kits themselves. Several areas were covered; they are discussed individually in the following sections.

1.3.7.1 Preventive Maintenance Checks, Service and Component Replacement

Chapter 3, Section IV of the UMARK Technical Manual (Kaman Aerospace Report No. R-2188) details Preventive maintenance checks, Service and Component Replacement. Preventive maintenance checks and servicing procedures for each item in the UMARK Kit are detailed in this section. Tests and inspections to determine whether an item is mission-capable and/or repairable are also included in this section.

1.3.7.2 Maintenance Allocation Chart (MAC)

Appendix A of the UMARK Technical Manual (Kaman Aerospace Report No. R-2188) contains the MAC Chart. The MAC chart assigns maintenance functions in accordance with the Aviation Maintenance concept for Army aviation. The chart designates maintainer's authority and responsibility for each component in the UMARK Kit. Any tools that are required for a particular operation on a particular item are also detailed in this section.

1.3.7.3 Repair Parts and Special Tools List (RPSTL)

Appendix B of the UMARK Technical Manual (Kaman Aerospace Report No. R-2188) contains the RPSTL. Included in this section is a repair parts list, defining the list of spares and repair parts required for each type of maintenance. No special tools are required for the UMARK Kit, as the Kits were specifically

designed to accommodate use and repair under adverse conditions. Each item in the UMARK Kit receives a source code, a maintenance code, and a recoverability code. The source code delineates how and where to get and item needed for maintenance, repair, or overhaul of an end item/equipment. The maintenance code defines the level(s) of organization that are authorized to use and repair items, and the type of repair allowed for each organizational level. The recoverability code indicates disposition of unserviceable items.

1.3.8 Kit Refurbishment

The Kits have been used extensively by the US Army and their customers. They have been used for a variety of tasks, from recovering downed aircraft to ferrying unflyable aircraft between maintenance and storage locations. Some of the components, chiefly the slings, have shown signs of wear from the repeated use, often in harsh conditions. In addition, some minor design changes came about due to testing and use (for instance, plastic-coated lanyard wire to replace the bare lanyard wire). The Kits were refurbished to return the worn components to new condition, replace those components which were expendable or not worth refurbishing, and bring all components up to the latest design.

2. Methodology

This section describes the design philosophy, methods and procedures used to design, analyze, and certify the UMARK Kit and its components.

2.1 Overall Design Philosophy

The guidelines for the overall design of the UMARK Kit were derived from the contract (DAAJ02-92-C-0048) as defined in "Annex A- Minimum Hardware Requirements" and "Annex B- Design and Performance Specification". Annex A specified the minimum quantities and types of hardware- containers, slings, and fittings, etc. The final UMARK configuration has evolved from the original "Annex A" requirements, and is much more universally applicable- it can handle more

aircraft than the original "Annex A" hardware list, and doesn't require any tools. Annex B called out functional requirements- the aircraft to be recovered (Ref. Table 1); damaged aircraft and extent of damage (Ref. Table 2); and expected installed equipment (i.e. mast-mounted sights) which must remain during recovery. Annex B also specifies limitations on rigging time and crew, environmental conditions, and Kit size. It also specifies aircraft weight, rigging locations and general configuration, loads and safety factors, and aerodynamic stability requirements.

The preliminary design process started with the maximum weight of the disabled aircraft as listed in "Annex B". Then the "Annex B" lifting combinations were analyzed to determine sling lengths and hardware requirements. However, the minimum hardware requirements for the UMARK Kit as defined by the contract in "Annex A" were also reflected in the analysis.

From this preliminary design study, the Static (Working) Loads were calculated for each element (i.e. Sling or Hardware) of a particular lifting combination. The Ultimate Load for each element was then determined by applying a safety factor of five (5), as defined in "Annex B", to the Static (Working) Load.

The ultimate load was then applied as the design load in the actual detailed design of slings and hardware for the UMARK Kit. A significant effort was made to minimize the final weight of the UMARK Kit by limiting the number of different sling lengths. This process involved selecting lengths that could be combined with other length slings, or folded to provide those lifting combinations identified in the preliminary design study.

Test articles of each component were produced and tested to the design ultimate loads. These test results were used as substantiation of the hardware to the final design.

2.2 Aircraft Reference Data

Aircraft reference data was supplied to Kaman by the US Army. Dimensional data included aircraft coordinate system and fuselage dimensions. Main rotor data included hub size, angle, and location; and main rotor blade dimensions and mounting details. Also included were tail boom and tail rotor dimensions, and landing gear dimensions and locations. Hardpoint dimensions and locations, and recommended lifting locations and prohibited areas were also included. Weights data included maximum gross weight of a recovered aircraft, and forward and aft CG locations. For rigging of damaged aircraft, additional data was provided. This including such items as maximum allowable loads at desirable or required lifting locations, and strength and stiffness data of various components. These components included lifting hardpoints, fuselage and tail boom. Much of this data was provided on an iterative basis as rigging configurations evolved.

2.3 Loads & Hanging Analysis Methodology

The method used to determine equilibrium hanging position and loads was an iterative force & moment balance. Input included sling lengths and stiffnesses; aircraft data including suspending locations, geometry, weight and CG; and aerodynamic data including drag coefficients, air velocity, and details of rotor blade position, area, and drag loads. With sling stretch and linkage geometry, element load and hang analyses were generally nonlinear and indeterminate. The process started with an assumed hang angle (usually 5° nose down). It calculated sling forces, sling stretch and resultant moment about the hanging location. The resulting hang angle was then calculated to bring the system into equilibrium, and the calculation was repeated. The final configuration was

required to meet the following criteria: a nose-down attitude of 0°-10°, no slack slings, no overloaded slings, and no interference. The process was iterated until convergence was obtained. The analysis converged or diverged after a few iterations; convergence indicated a solution, and divergence required a new geometry estimate.

2.4 Design & Testing of Slings & Fittings

The following sections describe the detail design, test article fabrication, and design substantiation testing performed on the UMARK components. The complete design, analysis, and testing program is documented in the "System Safety Hazard Analysis Report Airworthiness Substantiation Document for the UMARK", Kaman Aerospace Corporation Report No. R-2207, published 7-September-1995. This report was updated for the RAH-66 Comanche in a Supplement, Kaman Aerospace Corporation Report No. PR-5332, published 1-April-1998.

2.4.1 Detail Design

Detail design of slings, fittings, and hardware resulted in design of the items listed in Table 5. The current UMARK Kit content reflects the achievement of minimized total kit weight and the minimum number of slings (length and quantity) to meet the lifting combinations outlined above. The Kit also provides the flexibility to rig different aircraft in the future. It should also be noted that the Kit contents do not include the few additional items necessary to effect recovery of the RAH-66 Comanche aircraft. These aircraft have five rotor blades, necessitating addition of the items in Table 6.

2.4.2 Test Article Fabrication

Test articles of each component were fabricated per the final design. Fittings and hardware were fabricated by Kaman Aerospace Corporation; slings and blade tie-downs were fabricated by Cortland Cable Company. These test articles were then delivered to a certified subcontractor for testing.

2.4.3 Design Substantiation testing

Design substantiation testing consisted of static and ultimate load testing. Testing on all original components was performed by Dayton T. Brown. The 94C533-1 CH-47 Hook Thimble, the only component added following functional testing at AATD, was fabricated and tested by Cortland Cable. Kaman's Airworthiness Substantiation Document (submitted separately) details testing of all components.

Table 5 - UMARK Kit Components List

Item No.	Part No.	Description	Qty Per Kit	Box No.
1	94H501-1	Cross Bar Assembly	N/A	N/A
1.1	94J502-1	Cross Bar	1	2
1.2	94D505-1	Tube Assembly	4	2
2	94D509-1	Lifting Clevis Assembly	1	3
3	94D514-1	Shackle Assembly	1	3
4	94J516-1	Blade Sleeve Assembly	4	3
5	94D519	26.5K MBS Slings	N/A	N/A
5.1	94D519-1	150" (12.5 ft) Green/White Sling	4	2
5.2	94D519-2	153" (12.75 ft) Yellow/White Sling	4	1
5.3	94D519-3	208" (17.33ft) Red/White Sling	2	1
5.4	94D519-4	360" (30 ft) Blue/White Sling	2	1
5.5	94D519-5	120" (10 ft) Black/White Sling	1	1
6	94H520	100K MBS Slings	N/A	N/A
6.1	94H520-1	30 ft. Black/White Sling	2	1
6.2	94H520-2	30 ft. Black/White Sling (with bridle attachment)	1	1
7	94H521	Adjustable-Length Tie-Down	N/A	N/A
7.1	94H521-1	Adjustable-Length Tie-Down Sling	2	3
7.2	94H521-2	Sling Extension	4	3
8	94C522	Tie-Downs	N/A	N/A
8.1	94C522-1	Fixed-Length Tie-Down	4	3
8.2	94C522-2	Snapless Tie-Down	1	3
9	94D523-1	Sling Link Assembly	3	3
10	94C524-1	Box Link Assembly	3	3
11	94D527-1	OH-58D Sight Wedge	1	3
12	94D528-1	UH-1 Square Wedge	1	3
13	94D529-1	AH-1 Mast Wedge	1	3
14	94D530-1	OH-58A/C Mast Wedge	1	3
15	94H531-1	Blade Pole Assembly	1	3
16	1670EG029B3	Drogue Parachute	1	3
17	94C533-1	CH-47 Hook Thimble	2	3

Table 6 - Revised Components/Qty Required for RAH-66 Comanche

Item No.	Part No.	Description	Qty Per Kit	Box No.
4	94J516-1	Blade Sleeve Assembly	5	3
7.1	94H521-1	Adjustable-Length Tie-Down Sling	3	3
8.1	94C522-1	Fixed-Length Tie-Down	5	3

3. Documentation & Deliverables

3.1 Engineering Drawing Package

Table 7 contains a complete list of drawings produced under this program. These drawings were provided as contract deliverable items, in paper and CD-ROM

formats. These drawings document all detail parts, assemblies, components, and kit contents for the current UMARK kit.

Table 7 - UMARK Drawing List

Dwg No	Description
94J500	UMARK COMPONENTS KIT
94H501	UMARK CROSS BAR ASSEMBLY
94J502	UMARK CROSS BAR
94C503	UMARK Flange Bushing
94H504	FOAM FITTING
94D505	UMARK TUBE ASSEMBLY
94C506	UMARK- Tube
94D507	UMARK LUG FITTING
94C508	UMARK- Spring Lock
94D509	UMARK LIFTING CLEVIS ASSEMBLY
94D510	UMARK CLEVIS SUB-ASSEMBLY
94D511	UMARK PIVOT BLOCK
94C512	UMARK Locking Pin
94C513	Clevis Pin
94D514	UMARK SHACKLE ASSEMBLY- 40K
94C515	UMARK Spacer Sling
94J516	UMIVERSAL BLADE SLEEVE
94D519	UMARK SLINGS - 26.5K MBS
94H520	UMARK SLINGS - 100K MBS
94H521	TIE DOWN, ADJUSTABLE ASSEMBLY
94C522	TIE DOWN ASSEMBLY
94H523	UMARK SLING LINK ASSEMBLY
94C524	UMARK BOX LINK ASSEMBLY
94C525	UMARK BOX LINK
94C526	UMARK PIN, BOX LINK
94D527	OH-58D SIGHT WEDGE ASSEMBLY
94D528	UMARK UH-1 SQUARE WEDGE ASSEMBLY
94D529	UMARK AH-1 MAST WEDGE ASSEMBLY
94D530	UMARK OH-58 A/C MAST WEDGE ASSEMBLY
94H531	UMARK POLE ASSEMBLY
94C532	UMARK BOX LINK ASSEMBLY
94C533	UMARK CH-47 HOOK THIMBLE

3.2 Airworthiness Substantiation Document (ASD)

The Airworthiness Substantiation Document details certification test procedures, test results, and certificates of conformance for all detail parts included in the

original UMARK kit. It was submitted under separate cover upon completion of component testing, and was technical basis for airworthiness certification of the UMARK Kits. All component strength requirements and actual values cited herein were originally documented in the ASD.

3.3 Airworthiness Substantiation Document (ASD) Supplement

Two items were not included in the original ASD, as they were developed after it was published. Both required airworthiness certification, and were documented in the ASD Supplement, Kaman Report No. PR-5332. A detailed discussion of each is included in the following sections.

3.3.1 CH-47 Hook Thimble, P/N 94C533-1

Testing and use of the UMARK kits indicated that the CH-47 Cargo Hook shape caused the high-strength sling to ride forward on the hook, remaining near the point of the hook during flight. This condition was considered undesirable.

It was determined that an interface fitting was needed, which would conform to the CH-47 hook and stabilize the high-strength sling in the correct location on the hook. A number of design iterations and discussions occurred between AATD Technical personnel, Kaman Aerospace engineering, and Cortland Cable engineering. These efforts resulted in the design of the 94C533-1 CH-47 Hook Thimble. Following design, a thimble test article was fabricated and used for design substantiation testing. Thimble ultimate testing successfully completed with results provided in Table 3.

The 94C533-1 CH-47 Hook Thimble was designed, built, and tested after the ASD was published. It was covered separately in a supplementary document. The data contained in the ASD demonstrate the suitability of the UMARK kit and its components, to safely perform the aircraft recovery tasks for which it was designed.

3.3.2 RAH-66 Comanche Rigging Procedures

A subsequent contract authorized inclusion of the RAH-66 Comanche into the list of UMARK-recoverable aircraft. Rigging analysis was performed and documented in the ASD supplement. Section 3.6.2 describes this effort in further detail.

3.4 Unit Maintenance Aerial Recovery Kit Technical Manual

Rigging and recovery procedures are documented separately in the Unit Maintenance Aerial Recovery Kit Technical Manual, Kaman Report No. R-2188. This document covers rigging and recovery procedures for inoperative helicopters as listed in Table 1; rigging and recovery procedures for damaged helicopters as listed in Table 2; and Kit maintenance and repair procedures. This manual has been updated to include rigging and recovery procedures for inoperative RAH-66 Comanche helicopters, as directed under contract DAAJ02-97-M-0004.

3.4.1 UMARK Technical Manual- Paper Format

The UMARK Technical Manual was provided under separate cover, in camera-ready paper format (unbound) as well as in ready-to-use (bound) format. In addition, each UMARK Kit contains one copy of the bound paper manual.

3.4.2 UMARK Technical Manual- Electronic Format (CD-ROM)

The UMARK Technical Manual was provided under separate cover, on CD-ROM. It contains the complete text of the paper format manual, including all tables, graphics, etc.

3.5 Four Prototype UMARK Kits

Four UMARK Kits were fabricated and delivered. These kits were used in the ground testing and flight testing programs. During these programs, several minor modifications to the design were recommended, and the rigging procedures were

tested and fine-tuned. Once the design had been validated and the rigging procedure refined, the kits went into service.

3.6 Addendum for Contract DAAJ02-97-M-0004.

Contract DAAJ02-97-M-0004 was issued to develop rigging methods, procedures and instructions for the RAH-66 Comanche. This included hanging loads and rigging analyses. Kaman analyzed four cases, detailed in Table 1.

3.6.1 Inoperative RAH-66 Comanche Rigging

Contract DAAJ02-97-M-0004 was issued in 1997; this contract added the RAH-66 Comanche (inoperative, not damaged) to the list of UMARK-supported aircraft. Kaman was directed to determine and analyze rigging configurations and develop rigging procedures. This necessitated airworthiness substantiation of the rigging configurations (supplements to the ASD) and rigging procedures (supplements to the Technical Manual).

3.6.2 Comanche Hanging Loads and Rigging Analyses

Airworthiness substantiation of the Comanche rigging configurations is documented in Kaman Aerospace Report No. PR-5332. The Comanche recovery loads have been demonstrated to be within the allowable load limits for all slings and fittings. Loads on the airframe were not reviewed. Methods used were as documented in the Methodology section (section 2) of this report.

3.6.3 Comanche Rigging Instructions

Rigging instructions were developed for 1-hook short and long line, and 2-hook short and long line. These analyses are reported in Kaman Aerospace Report No. PR-5331. The UMARK Technical Manual has been updated to include these rigging instructions.

4. Summary

The UMARK kit is currently capable of facilitating recovery of a wide range of inoperable aircraft (Ref. Table 1 for the complete list). Most aircraft can be

recovered even after sustaining significant damage to certain major systems (Ref. Table 2 for the complete list). The kit and its components have been demonstrated safe and airworthy via component strength testing (documented in the ASD) and functional testing by AATD. Four prototype kits have been in service for approximately three years, and have met with approval by all users.

5. Recommendations for Future Work

5.1 Sling Modifications

Since the inception of this program, advances in sling morphology have provided the basis to believe that even lighter weight slings may be possible. It is recommended, based on additional weight savings, that an investigation of the latest sling technology be conducted. Additionally, expansion of the UMARK to include other aircraft is possible. This may include commercial rotary wing as well as commercial and military fixed wing aircraft. Fixed wing aircraft require some use of belly bands to effect their recovery. Therefore, investigations should be conducted to not only expand the applicability of the UMARK to other aircraft, but to look into the use and design of Spectra-type belly bands for fixed wing recovery.